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Operating in the Space Environment: A Spacecraft Charging Study of the Advanced X-ray Astrophysics Facility-Spectroscopy Spacecraft*

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Introduction

Among the natural space environments impacting the design and operation of spacecraft in orbits around the Earth are the geomagnetic field, the Earth's gravitational field, ionizing radiation, meteoroid/orbital debris, the neutral thermosphere, the ambient plasma, and the solar and thermal environments. The spacecraft interacts with these environments as it progresses along its orbit, and these interactions can cause a range of effects which may interfere with the operations of the spacecraft. One interaction in particular, the interaction between the spacecraft and the ambient plasma, causes a phenomena known as spacecraft charging. Spacecraft charging is the accumulation of charged particles on the exposed surfaces of a spacecraft.

The effects attributed to spacecraft charging can be a serious engineering concern. Scientific instruments designed to measure properties of the natural space environment may have readings that are compromised due to the buildup of electric fields around the spacecraft. Charged surfaces may attract ionized contaminants, causing an increase in surface contamination. ARc-discharging is a rapid release of large amounts of charge. These discharges can cause physical surface damage and the discharge process can generate large structural currents which, when coupled into spacecraft electronics, can cause upsets and anomalies. Arc discharging is seen as the primary means by which spacecraft operations is disturbed by spacecraft charging.

The effects of spacecraft charging bring about a need for space programs to adopt a plan to evaluate the impact of spacecraft charging related effects on spacecraft operations. This plan would be, in effect, a spacecraft charging protection plan. This protection plan involves defining the natural space plasma environment to which the spacecraft will be exposed, performing analyses to determine how interactions between the environment and spacecraft will affect the mission goals and objectives, and developing engineering design guidelines for the purpose of reducing or negating spacecraft charging related effects.

Several of the key elements needed for a protection plan were addressed through a joint Air Force/NASA effort started in 1975. Plasma properties were defined through flight experiments, and interaction phenomena were studied using space- and ground-based experiments. Products of the joint effort include environment definition documentation, generic engineering design guidelines, and computer codes designed to simulate the interaction between spacecraft and the environment. The Potential Of Large spacecraft in Auroral Regions (POLAR) computer code was developed to analyze spacecraft charging at high-inclination low-earth orbits caused by the encounter with the energetic particles of the auroral regions. POLAR considers the significant charging currents and geometric electric field effect to model the buildup of charge and electric fields on and around a spacecraft. Surface voltage levels attained by the three-dimensional model of the spacecraft assist in evaluating the probability and location of arc discharges on the spacecraft.

This study presents the results of a spacecraft charging effects protection study conducted on the Advanced X-ray Astrophysics Facility-Spectroscopy (AXAF-S) spacecraft. The AXAF-S was in development at the NASA Marshall Space Flight Center when the project was canceled in October of 1993. AXAF-S was to be a part of NASA's Great Observatories and was to measure high energy X-rays, emitted from such objects as black holes, neutron stars, and quasars. The AXAF-S spacecraft was to fly in the late 1990's.

Charging of the AXAF-S spacecraft due to auroral region environment is modeled using the POLAR computer code. Charging levels of exterior surfaces and the floating potential of the spacecraft relative to the ambient plasma are determined as a function of the spacecraft design, operational configuration, and orbital conditions. Areas where large surface voltage gradients exlsts on the AXAF-S spacecraft are identified as possible arc-discharge sites. Results of the charging analyses are the used to develop design recommendations that will limit the effects of spacecraft charging on the AXAF-S operation.

AXAF-S Geometry

The AXAF-S spacecraft (see Figure 1) consists of a 4m optical bench (0.75m in diameter), a 1090 liter, 2m diameter Dewar bottle surrounding the science instruments (for cooling of the X-ray calorimeters) mounted at the end of the optical bench, and a 1.8m X 2m X 1.4m electronics mounting structure (known as the "spacecraft bus") built around the aft half of the optical bench. The two solar array wings (6.2m X 2m each) are mounted to the "spacecraft bus".

Factors Influencing Charging in High-Inclination Orbits

In high-inclination (polar) orbits, most of the adverse effects caused by spacecraft charging depend on the levels of differential charging that occur on the spacecraft. This is characterized by parts of the spacecraft charging to different potentials relative to each other. Differential charging can result in arc-discharges if the electric field between different regions exceeds breakdown thresholds.

Several factors influence the level of differential charging that occurs for given charging environment characteristics. Most depend on the electrical properties of the spacecraft outer surface materials. These include the amount of dielectric material that comprises the spacecraft outer surface area and electrical bonding of the conductive surface materials. Presently, the only sure way to eliminate differential charging is to make the entire outer surface of the spacecraft conductive and electrically bond all outer surfaces to the spacecraft structure ground.

Modeling Summary

The charging behavior of the AXAF-S was studied for several orbital configurations and operational modes. Modeling was concentrated on the 2400 local time as the spacecraft entered the auroral oval. This configuration was selected since this has been demonstrated to be the region where charging is most likely to occur. Operational orientations were studied to determine the worst orientations from a charging point-of-view. The surface materials selected were the ones that had been selected by the AXAF-S engineers at the time of the study.

AXAF-S Charging Behavior

The main purpose of this study is to determine whether the differential potentials which develop on the AXAF-S spacecraft are large enough to cause concerns about arc-discharge. The potentials ($\sim$1 kV) on the thermal control coatings of the Dewar bottle are large enough to suggest that "punch-through" discharges could occur and degrade the thermal control properties of the Dewar coating. This could result in degraded scientific instrument capabilities and shortened instrument lifetime.

Based on the results of the charging analysis, design recommendations are made that limit the detrimental effects caused by spacecraft charging on the operation of the AXAF-S.

Figure 1 AXAF-S Spacecraft